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PROBLEM OF CROSS-IDENTIFICATION OF POINT SOURCES

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Abstract. At the Belgrade Astronomical Observatory (AOB) an original programme for the cross – identification of the point sources of any two catalogues with enough data is developed. As an example the results of the cross – identification between HIPPARCOS (HIgh Precision PARallax COllecting Satellite) and 2MASS (Two Micron All Sky Survey) is presented. The programme is based on the 3σ rejection criterion and it is adequate for the cross – identification of new catalogues of millions of stars. In the basic selection of the example there were 117 955 HIPPARCOS stars and 162 195 232 2MASS Second Incremental Data Release ($\sim$ 47% of the sky) ones, and it was found a big amount of common stars by using only the data of catalogues. In the second step, the preliminary calculated systematic error (near $0.''10$) of differences $\Delta\alpha$ and $\Delta\delta$ of detected common stars was included into the programme, and the new result of the cross – identification was significantly better. This paper is the part of nowadays efforts to link big stellar catalogues in the visiblly, infrared and other wavelengths to the ICRF (International Celestial Reference Frame).

1. INTRODUCTION

After a decision of the IAU (International Astronomical Union) General Assembly (Kyoto, 1997) the ICRF was adopted to materialize the ICRS (International Celestial Reference System) from the beginning of 1998. The HIPPARCOS Catalogue (ESA 1997) is considered as the primary optical counterpart of the ICRF from 1997.

The ICRF is based on a catalogue of 608 compact radio sources (Ma et al., 1998) which are determined with an internal precision of 0.3 to 0.5 mas (milliarcsecond). It has been updated recently by the ICRF – Ext.1, which includes 59 new sources (IERS Annual report 1999).

The HIPPARCOS contains near 118 000 stars. They are brighter than magnitude 12 and mostly range between $V = 7$ and $V = 9$. It is far too restricting nowadays when searching reference stars for astrometric calibration. The mean density is less than 3 stars/square degree. It is not enough to insure a suitable astrometric reduction in the case of observations carried out in small fields with CCD detectors. Therefore it is necessary to produce large stellar catalogues with fainter sources (in the visible and in the infrared) and linked to the ICRF. The HIPPARCOS stars positions and proper motions are bases of the optical frame HCRF (Hipparcos Celestial Reference Frame). The HIPPARCOS Catalogue gives for each object: the position with an accuracy of the order of 1 mas at the epoch of the catalogue 1991.25, the proper

motions in $\mu_\alpha \cos\delta$ and μ_δ with a standard error of about 1 mas/yr, and very large number of other parameters.

There are various recent catalogues useful for the densification of the ICRF, at optical and other wavelengths (infrared, radio, X, etc.): the Tycho-2 Catalogue, the USNO CCD Astrograph Catalogue (UCAC), the 2MASS, DENIS (Deep Near Infrared Survey of the Southern Sky), etc. The 2MASS is the project of the near infrared sky which is based on two highly automated 1.3 m telescopes for both hemispheres, equipped with a three channel camera. The sky was observed simultaneously at J (1.25 microns), H (1.65 microns) and K_S (2.17 microns).

The 2MASS Second Incremental Data Release includes a Point Source Catalogue (PSC), with positions and photometry for 162 213 354 sources, an Extended Source Catalogue (XSC) with positions and photometry in the three survey band passes for 585 056 objects and an Atlas Images (1 897 017 FITS images in the three survey bands). The 2MASS catalogue was a joint project between the University of Massachusetts and the Infrared Processing and Analysis Center California Institute of Technology (Cutri et al., 2001), with observing facilities at Mt. Hopkins – AZ for the northern hemisphere and Cerro Tololo – Chile for the southern one. The 2MASS telescopes maped the sky by using a freeze – frame scanning technique, and operated by the Smithsonian Astrophysical Observatory (SAO) and the National Optical Astronomy Observatories (NOAO). The 2MASS was formed by the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF).

The PSC of the 2MASS Second Incremental Data Release has been divided onto 49 right ascension segments, $0^h \leq \alpha < 24^h$, ordered by increasing declination within each segment. The data are covering 19 681 square degrees, which means about 47% of the sky. The relevant observations were carried out between 1997 June 7^{th} and 1999 February 20^{th} (329 northern and 239 southern nights with at least one photometric period). The magnitude limits are: 15.8 mag for J band, 15.1 mag for H one, and 14.3 mag for K_S one. The final 2MASS catalogues contain about 470 million stars and 1.6 million galaxies. The positions are accurate to $< 0.''2$, and α and δ done for J2000. Each star has got the epoch of observation. The positions of the 2MASS sources are correlated with the ACT or USNO-A optical catalogues, and are tied to the ICRS via the ACT Reference Catalogue. Some positional solution may have a random walk as much as $1.''0$ from the ICRS frame. About 77% of the PSC objects have $|b| < 20^o$ (the majority of point sources are concentrated towards the Galactic plane). Some data from the ACT (Urban et al., 1998) or USNO-A catalogues are included in the 2MASS PSC records, but these are not identifications between the infrared and optical sources. These are only associations, and the optical associations for the 2MASS sources are found using a simple closest positional algorithm. The astrometric accuracy of 2MASS PSC was reached via the comparison of the positions of stars in the PSC with those in the Tycho-2 and UCAC catalogues (which are not used in 2MASS position reconstruction). The accuracy of 2MASS positions is on line with the number and distribution of ACT astrometric reference stars in each tile.

As the example, the author did the cross – identification of HIPPARCOS – 2MASS PSC stars. The cross – identification results, based on the programme of 3σ criterion, are hopeful for similar jobs of the cross – identification of new big stellar catalogues.

2. THE CROSS – IDENTIFICATION PROGRAMME

The cross – identification programme is explained via the example HIPPARCOS – 2MASS. The rejection criterion was set to a 3σ value. The 2MASS PSC positions comparison was made with respect to the positions given by the HIPPARCOS Catalogue. The mean density of HIPPARCOS Catalogue is about 3 stars/sq.deg., while 2MASS one is near 8 242 stars/sq.deg. The cross – identification programme passed through each of 49 segments adopted for 2MASS, and made it only into 3^m long α respective segments (not across the all celestial HIPPARCOS sphere for each 2MASS star). It was made the matrix with the information about the 3^m segments locations for the HIPPARCOS Catalogue and that 3^m segments of α are changeable in the programme (can be longer or shorter in line with the information of errors of positions). In that way, for a suitable limited HIPPARCOS zone of the sky, each 2MASS star was compared with some numbers of HIPPARCOS ones. The identification was considered as effective when the HIPPAROCS star could be coupled to only one 2MASS star within a 3σ vicinity in both coordinates (α and δ).

The method was tested before the beginning of the cross – identification programme. It was done inside a very small part of the sky including just few HIPPARCOS known stars to check the quality of the results. After that, the programme was ran within the 49 mentioned 2MASS segments. Some stars were without enough data and these stars were removed before beginning the cross – identification programme. Therefore 18 122 stars, which represent about 0.01% of the 2MASS PSC were removed from this catalogue. In a similar way, 263 stars were removed from the HIPPARCOS Catalogue (about 0.22%), because of the absence of the proper motion data. Finally, there were 117 955 HIPPARCOS stars for the cross – identification.

For each star, the standard deviation σ was calculated, both in the α direction and in the δ one, respectively σ_α and σ_δ, by using HIPPARCOS and 2MASS data. There were enough data to do it. The calculated value of σ_α (and σ_δ) depends of few parts, $\sigma_\alpha^2 = \sigma_{\alpha 1}^2 + \sigma_{\alpha 2}^2 + \sigma_{\alpha 3}^2 + ...$ (and $\sigma_\delta^2 = \sigma_{\delta 1}^2 + \sigma_{\delta 2}^2 + \sigma_{\delta 3}^2 + ...$). The values $\sigma_{\alpha 1}$ and $\sigma_{\delta 1}$ are on line with the standard errors of the HIPPARCOS positions, and calculated by using the HIPPARCOS data. The values $\sigma_{\alpha 2}$ and $\sigma_{\delta 2}$ are on line with the observational epochs difference between HIPPARCOS and 2MASS (both catalogues data) and the errors of proper motions $\mu_\alpha \cos\delta$ and μ_δ (from HIPPARCOS data). The values $\sigma_{\alpha 3}$ and $\sigma_{\delta 3}$ are on line with the position error ellipse, and calculated by using the 2MASS data.

The epoch of HIPPARCOS observations is 1991.25, and each star of 2MASS PSC has its own epoch of observation. Because of it, it was necessary to take into account the standard error rate for the proper motions influence by using the values of $\mu_\alpha \cos\delta = \mu_{\alpha *}$, μ_δ and the epoch differences t (in years). Therefore, the positions in both catalogues are on line with J2000.0 epoch. Before carrying out the cross – identification programme by using $3\sigma_\alpha$ rejection threshold in the α direction and $3\sigma_\delta$ one in the δ one, the author took into account the changes of the HIPPARCOS coordinates α_H and δ_H due to the epoch differences t (in years) by using the HIPPARCOS proper motions $\mu_{\alpha *}$ and μ_δ: $\alpha_{Hipp} = \alpha_H + \mu_{\alpha *} t / \cos\delta$ and $\delta_{Hipp} = \delta_H + \mu_\delta t$, where α_{Hipp} and δ_{Hipp} are at the epoch of 2MASS observations. The cross – identification programme

identifies the common star if its position satisfies $\alpha_{Hipp} - \alpha_{2MASS} = \Delta\alpha < 3\sigma_\alpha$ and $\delta_{Hipp} - \delta_{2MASS} = \Delta\delta < 3\sigma_\delta$.

It was found 37 940 common stars, which represents about 32.2% of the 117 955 HIPPARCOS stars in our basic selection. Because of the fact that the 2MASS Second Incremental Data Release covers about 47% of the sky, this means that the cross – identification programme is near 70% successful. If the systematic error between HIPPARCOS and 2MASS coordinates is less than 0."1 (in line with the author preliminary investigations about the systematic discrepancies of HIPPARCOS-2MASS coordinates), and put it into the programme, it is possible to reach near 80 % of common stars.

Only two unsuccessful cross – identifications (of 37 940 common stars) have been found: each of the HIPPARCOS stars H16658 and H85045 can be associated with two 2MASS objects. In the HIPPARCOS Catalogue, the star H16658 is noted as a single star, but the star H85045 is noted as a double star (WDS17229+1628, J1248 AB). From the results presented here, both H16658 and H85045 are close double stars, or maybe the star H16658 is not double, but there is another one with close coordinates.

3. CONCLUSION

In this paper, only two unsuccessful cross – identifications of 37940 detected common stars have been found. These two cases are close double stars or just near each other on the sphere: H85045 is already marked as a double star (WDS17229+1628), H16658 is marked as the single star in the HIPPARCOS Catalogue. For these kinds of cases it is necessary to include the cross – identification part with photometric data into the programme.

The cross – identification of HIPPARCOS – 2MASS stars are presented by using the programme based on the 3σ criterion and the information of the positions of stars, the proper motions, etc. It is on line with the similar actions about the cross – identifications of new catalogues of millions stars.

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